The rare, old-aged conifers of El Malpais— Their role in understanding climatic change in the American Southwest

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Introduction

In the mid-1940s ecologist Alton Lindsey began a systematic floristic study of the area later to become El Malpais National Monument. This research, subsequently published in the journal *Ecological Monographs* (Lindsey, 1951), was the first comprehensive survey of the flora of the malpais in relation to the unique habitats found on the lava flows. The monograph particularly emphasized the unique nature of various species of trees, shrubs, mosses, and algae. Lindsey discovered entire stands of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), piñon (*Pinus edulis*), and various species of juniper (*Juniperus* spp.) trees existing in areas with little soil throughout the malpais. In his many excursions onto the lava flows, Lindsey also discovered that both Douglas-fir and ponderosa pine trees growing on the malpais lava reached great ages. He cored numerous trees to investigate the relationship between tree growth and substrate material.

More than 40 years later, we sampled in the same areas and confirmed that these trees hold great potential for revealing past climatic trends over the last 1,000–2,000 years. Using dendrochronology, the science of tree-ring dating, researchers can absolutely date to the exact year of formation each tree ring formed by the malpais trees over their respective lifespans. Because tree growth is strongly associated with regional climate (Fritts et al., 1965; Fritts, 1976), dendroclimatologists (scientists who use tree rings to study past climate) can measure the width of each individual tree ring and determine the rainfall in any given year long before climate records were kept. Furthermore, by reconstructing climate from tree rings, dendroclimatologists can learn about past *long-term* trends in climate and determine whether extended periods existed in the past when climate was particularly favorable or unfavorable for human and plant populations when compared to modern climate records. We can then relate these long-term climate trends to our knowledge about the behavior of the Ancestral Puebloan culture of the Four Corners area of the Southwest. This leads to an intriguing question asked by many archaeologists and visitors to the abandoned ruins of the Southwest: Could climate have been partially responsible for the abandonment and migratory behavior of these ancient inhabitants? Perhaps the old-aged conifers of the malpais can provide some answers to this long-perplexing question.

How trees can grow on the lava surfaces

The presence of trees on the lava flows at first appears paradoxical: How is it possible for such humid-site trees like Douglas-fir and ponderosa pine to exist on the seemingly harsh lava surfaces with little soil and an apparent lack of water? Our field reconnaissance essentially supported the observation first made by Lindsey (1951) that the lava flows support a more mesophytic vegetation type (i.e. plants that grow in more humid conditions) than areas off the lava flows. This observation suggests that the lava substrate somehow alters environmental conditions to allow certain species to exist in areas that would otherwise be considered inhospitable. This further suggests that the ability of the lava substrate to retain moisture is important in determining the distribution of plants throughout the malpais (Lindsey, 1951). We hypothesize, as did Lindsey, that the porous nature of the lava acts as a reservoir that traps and holds moisture from winter snowmelt and summer monsoonal rainfall. Ice caves that occur throughout the malpais provide evidence that the lava may act as a special type of aquifer. The lava therefore retains water necessary for Douglas-fir and ponderosa pine establishment and continued propagation.

Sampling the living malpais trees

Following our initial sampling efforts in 1990, we began an extensive systematic sampling during the next four years, specifically targeting long-lived Douglas-fir and ponderosa pine trees found growing at two locations on the surface of the Bandera lava flow (Fig. 1): (1) along the perimeter of the lava tube just south and west of Bandera Crater, and (2) northeast of Cerro Rendija, a site now known as the Lindsey Site. We confirmed what Lindsey (1951) had previously described regarding the unusual growth forms of individual trees. Most Douglas-fir trees are short, seldom more than eight meters in height, very wide at the base, and often exhibit a near-horizontal spiral grain (Figs. 2, 3). These traits are usually indicative of great age in conifers (Schulman, 1937). We found ponderosa pine trees to be similarly influenced by the lava substrate. On the McCartys lava flow, west of The Narrows and surrounding McCartys Crater, the forest consists of stunted pine trees that rarely reach three meters in height (Fig. 4). However, the pines can reach great heights in well-watered areas off the lava flow, such as near Three Kipukas and Cerro Bandera.

To obtain tree-ring samples from living trees, we used increment borers (a hollow metal tube screwed into the tree) to extract pencil-thin cores of wood from the old-aged conifers. The coring process removes very little living wood tissue, and the sampled tree seals the small wound in a few weeks.

Sampling the remnant wood in the malpais

Initially, we concentrated on the living old-aged conifers, but soon discovered numerous samples of old wood lying on the lava surface that appeared to be well-preserved (Figs. 5, 6). To extend the tree-ring calendar back in time, dendrochronologists often sample

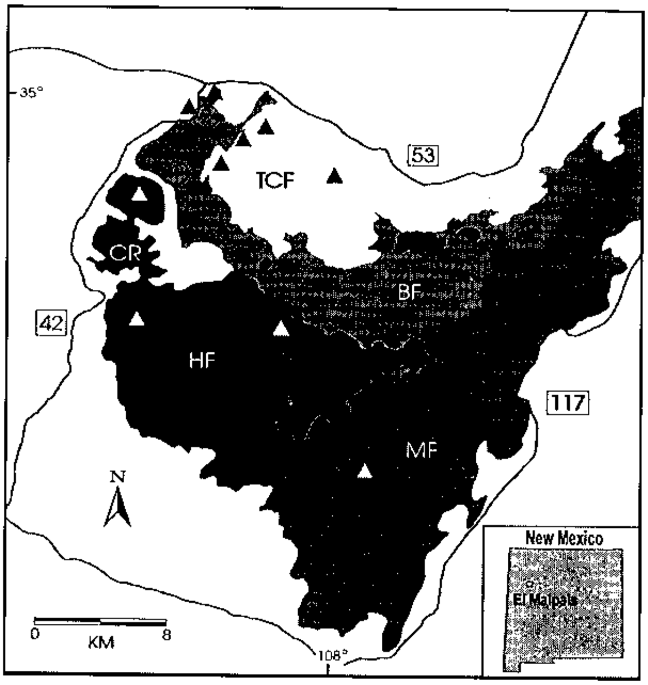

FIGURE 1—El Malpais National Monument, showing locations of the Cerro Rendija East (or Lindsey) site (1) and the Bandera Ice Cave site (2) in the Bandera lava flow (BF). Other lava flows include Twin Craters (TCF), McCartys (MF), Hoya (HF), and Cerro Rendija (CR). Triangles denote prominent volcanic vents.

FIGURE 2—A living Douglas-fir tree, CRE-37, showing the typical growth form found on the lava flows. CRE-37 dates to A.D. 1062.

dead wood, then match the outer pattern of wide and narrow tree rings from this dead wood with the identical pattern from the living trees. Matching the unique patterns of rings to date samples of unknown age is a technique known as crossdating, which uses both graphical and statistical methods to ensure exact year assignment to each individual tree ring (Stokes and Smiley, 1968; Holmes, 1983). The malpais contained abundant remnant wood that we knew could be used to extend our climate reconstruction even further back in time.

Using an increment borer on the remnant wood was not feasible, because the brittle wood repeatedly breaks inside the borer. Therefore, we used a chainsaw to remove complete and partial cross sections from Douglas-fir and ponderosa pine logs and smaller pieces of remnant wood.

Ages of the malpais trees

Once all samples had been mounted and sanded, we used a microscope to view the tree rings and graphically crossdate all tree rings from all cores and cross sections. We learned that El Malpais National Monument contained some of the oldest living trees, as well as the oldest sections of remnant wood, ever dated in the greater American Southwest. The two oldest living Douglas-fir trees, samples BIC-63 (inside ring date of A.D. 719) and CRE-37 (inside ring date of A.D. 1062), are the oldest confirmed, crossdated individuals for this species yet discovered in North America (Table 1). We found numerous Douglas-fir trees growing on the Bandera lava flow with ages in excess of 600 years. Given the very small area sampled, we believe that the malpais likely contains several individual Douglas-fir trees more than 1,000 years old. The living trees gave us a continuous, well-replicated tree-ring chronology back to A.D. 719, but the number of trees in our sample with rings prior to A.D. 1000 was low. A climate reconstruction based solely on living trees would not have been reliable prior to A.D. 1000.

The remnant wood solved this problem. The first remnant specimen collected was sample CRE-46, a section from the base of a ponderosa pine tree that once grew in the malpais (Fig. 6). Neither modern collection chronologies nor archaeological reference dating chronologies from New Mexico sites could date this sample. We had to turn to longer and older archeological tree-ring chronologies from outside the state, specifically those from Canyon de Chelly (Arizona) and Durango (Colorado). This decision was both crucial and fortunate, because eventually we were able to date this tree back to the year A.D. 111 using the Durango reference tree-ring chronology. We had, with this one high-quality, well-preserved specimen, a sample of a tree older than any other yet collected in New Mexico.

The effort to extend the malpais tree-ring chronology back in time continued as sample after sample of remnant wood dated prior to A.D. 1000, very effec-

FIGURE 3—A living Douglas-fir tree, BIC-63, showing an atypical growth form in which the main stem has died, yet the root system remains intact and supports a lateral branch regrowth. This tree has an inside-ring date of A.D. 719 and is currently the oldest known living Rocky Mountain Douglas-fir tree in North America.

FIGURE 4—A living ponderosa pine tree on the McCartys lava flow, showing the stunted and contorted growth form typical of pine trees growing on this lava flow.

tively linking the living-tree chronology with the remnant-wood chronology. Eventually, we collected sections from 28 trees that had tree-ring sequences extending prior to A.D. 1000 (Table 2), more than any other site, archaeological or modern, studied in the

TABLE 1—Inner- and outer-ring dates (yrs A.D.) of 10 oldest living trees sampled in the malpais. All samples are from Douglas-fir trees.

Number	Sample ID	Inner ring	Outer ring	Length
1	BIC 63	719	1992	1274 yrs
2	CRE 37	1062	1990	929
3	CRE 121	1147	1992	846
4	BCS 06	1235	1991	757
5	BCS 09	1256	1990	735
6	BIC 30	1288	1989	702
7	BFL 01	1293	1990	698
8	BIC 06	1294	1989	696
9	CRE 59	1298	1991	694
10	CRE 29	1316	1990	675

FIGURE 5—A remnant of a Douglas-fir tree, sample CRE-51, found lying on the surface of the Bandera lava flow. This sample has an inside-ring date of A.D. 706.

FIGURE 6—Remnant of a ponderosa pine tree, sample CRE-46, found lying on the surface of the Bandera lava flow. This sample has an inside-ring date of A.D. 111.

Southwest. The most remarkable remnant sample collected was CRE-148, a section from a Douglas-fir log found at the Lindsey site on July 25, 1993. This tree, now known as the Bannister Tree in honor of the eminent dendrochronologist Dr. Bryant Bannister, had an inside tree ring crossdated to 200 B.C. and an outer ring dated to A.D. 550, making this currently the oldest dated wood in either Arizona or New Mexico. Unfortunately, we could not include the innermost 64 rings from this sample in the final chronology because they were too compressed for accurate ring measurement.

We made another breakthrough during that same field trip in the summer of 1993. We had previously concentrated our sampling to only Douglas-fir and ponderosa pine trees because wood from these two species was by far the easiest to crossdate. We collected a cross section from a remnant Rocky Mountain juniper (*Juniperus scopulorum*) tree found near the lava tube just south of Bandera Crater, and were surprised at the ease with which this sample dated. This tree also provided us with a continuous tree-ring sequence

TABLE 2—Inner- and outer-ring dates of 10 oldest sections of remnant Douglas-fir (DF) and ponderosa pine (PP) wood that extend prior to A.D. 1000.

Number	Sample ID	Inner ring	Outer ring	Length	Species
1	CRE 148	200 B.C.	A.D. 550	751 yrs	DF
2	CRE 184	A.D. 103	A.D. 216	114	PP
3	CRE 46	A.D. 111	A.D. 456	346	PP
4	CRE 117	A.D. 118	A.D. 734	617	DF
5	CRE 110	A.D. 128	A.D. 525	398	PP
6	CRE 186	A.D. 502	A.D. 610	109	PP
7	CRE 109	A.D. 567	A.D. 874	308	PP
8	BIC 74	A.D. 589	A.D. 1089	501	DF
9	CRE 45	A.D. 599	A.D. 1349	751	DF
10	CRE 174	A.D. 664	A.D. 1164	501	DF

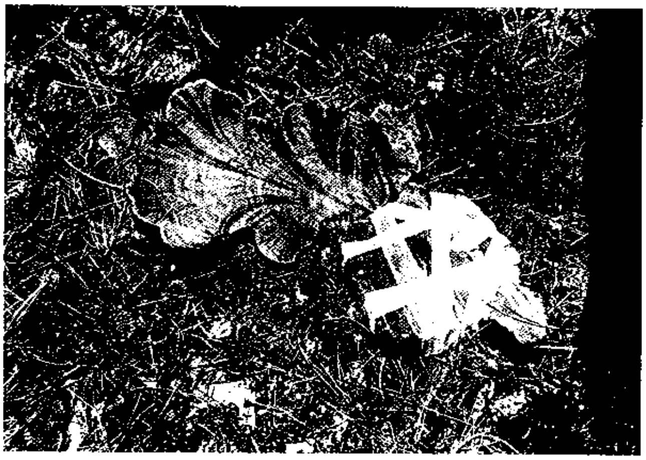

FIGURE 7—Cross section of a remnant Rocky Mountain juniper, sample CRE-175. This juniper germinated in approximately 29 B.C. and died in A.D. 1859, making this the oldest known tree to have lived in the American Southwest.

extending from A.D. 318 to A.D. 1459. A cross section cut later from another Rocky Mountain juniper log, sample CRE-175, showed this tree had germinated on the Bandera lava flow in the year 29 B.C. This tree then lived for 1,888 years until the year A.D. 1859 when it died, making this the oldest known tree to have lived in the American Southwest (Fig. 7). We are confident that the malpais contains 2,000 year-old living juniper trees, and perhaps even older ones as well. We hope to eventually collect additional juniper specimens from the malpais to complete a well-replicated juniper tree-ring chronology.

After several years of continuous tree-ring dating, we eventually dated 248 Douglas-fir and ponderosa pine tree-ring series. We averaged together annual indices of tree growth derived from the raw measurements, a process known in dendrochronology as chronology building (Fritts, 1976), to develop a 2,129 year-long tree-ring chronology back to 136 B.C. The malpais tree-ring chronology is currently the longest single-site chronology in the greater American Southwest.

Developing the climate reconstruction

Before we could reconstruct climate, we first had to determine to which climatic variables the trees were responding. Using correlation and response function analyses, statistical techniques commonly used by dendroclimatologists (Fritts, 1976), we found the strongest relationship between tree growth and total precipitation extending from July of the previous

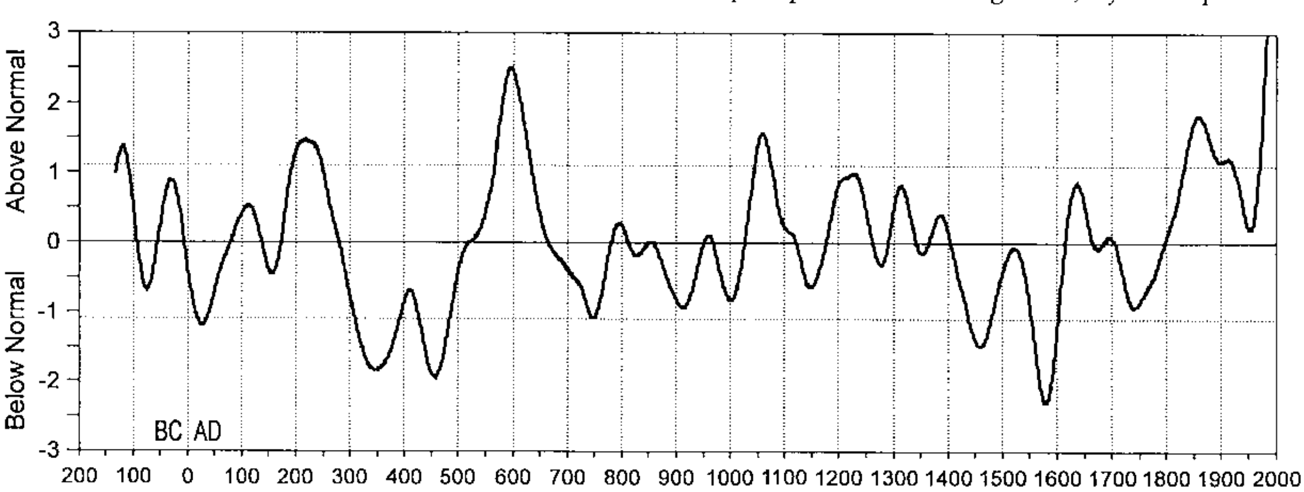

FIGURE 8—The final reconstruction of total annual (July–July) precipitation for the period 136 B.C.–A.D. 1992 based on the malpais trees and presented as a smooth curve fit through the actual yearly reconstructed values. The curve accentuates long-term (more than 100 years) trends in past climate. Sections on the curve above or below the 1.1 level (dashed lines) are considered very wet or very dry climate periods.

year to July of the current year, a period commonly termed in hydrology a "water year" as opposed to a calendar year. This relationship indicates the malpais trees are responding more to hydrological than to direct climatic factors because the lava flows tend to retain water year-round. This long response was fortunate because it allowed us to reconstruct annual total precipitation rather than rainfall for only one season, such as winter or spring.

The reconstruction was carried out by first calibrating widths of tree rings with annual (July–July) precipitation for the malpais area over the historic period when weather records were kept (1895–1992). The calibration was conducted using an ordinary least-squares regression to develop a linear equation that predicted annual rainfall for any particular year from the tree-ring width for the same year. Essentially, the statistical calibration allows us to say that a tree-ring width of so many millimeters resulted from annual precipitation totaling a specific amount. Once the calibration was completed, we were able to reconstruct annual rainfall for the malpais area spanning the entire length of the tree-ring chronology, back to 136 B.C.

The climate of the malpais area over the past 2,100 years

A smooth-curve fit through the climate reconstruction revealed that climate in northwestern New Mexico between 136 B.C. and A.D. 1992 was dominated by seven alternating, long-term periods of above normal and below-normal rainfall (Fig. 8, Table 3), which correlate very well with long-term fluctuations reconstructed from other paleoenvironmental reconstructions (Euler et al., 1979). These long-term periods also provide additional information on past environmental changes that may have affected behavioral characteristics of the populations that lived in northwestern New Mexico during the last 2,100 years. Our results also provide an opportunity to independently compare the malpais tree-ring reconstruction with paleoenvironmental reconstructions for the Four Corners area developed using other techniques based on geomorphic, archaeological, and stratigraphic evidence of past environmental change (Euler et al., 1979).

A period of above-normal rainfall between A.D. 81 and 257 correlates very well with a fluvial maximum that occurred in the Four Corners area of the Southwest prior to A.D. 230 (Euler et al., 1979). In some portions of the Four Corners area, such as southeastern Utah and southwestern Colorado, local populations increased during this period (Dean et al., 1994). However, this favorable period was followed by the most severe long-term drought period (A.D. 258–520) in the last 2,129 years. Tree growth was noticeably reduced during this period, especially beginning near A.D. 350. Euler et al. (1979) and Dean et al. (1985) reported that a prolonged hydrologic minimum occurred between A.D. 250–450, which correlates very well with this prolonged drought. Interestingly, the differentiation of the three major Southwestern cultures, Hohokam, Mogollon, and Ancestral Puebloan, accelerated during this unfavorable period (Gumerman and Gell-Mann, 1994), suggesting that differentiation, migration, and other changes in behavioral patterns may have occurred as a means to cope with changing environmental conditions.

Between A.D. 100 and 550 the human population of the entire greater Southwest experienced little change, which was followed by a dramatic increase, especially in the Colorado Plateau area (Dean et al., 1994). The malpais climate reconstruction shows that a major climatic change began occurring around A.D. 550, with annual rainfall increasing to extremely high levels between A.D. 521 and 660. During this favorable period Basketmaker populations increased throughout the Four Corners region, especially in southwestern Colorado and southeastern Utah, the Kayenta area, and the San Juan Basin (Dean et al., 1994). This very favorable period was followed by a long period of below-normal rainfall between A.D. 661 and 1023. Interestingly, the Ancestral Puebloan population continued to increase during this unfavorable period, indicating that long-term, low-frequency fluctuations in climate had little influence on regional populations (Dean et al., 1985). Other studies (Schoenwetter, 1970; Eddy, 1974; Euler et al., 1979) also confirm that a hydrologic minimum occurred between A.D. 661 and 1023.

Favorable climate conditions returned between A.D. 1024 and 1398, a period that correlates very well with above-normal hydrologic conditions reconstructed by Euler et al. (1979). However, two major short-term droughts occurred during this period that doubtless had prolonged effects on the Ancestral Puebloan population. A secondary hydrologic minimum and its corresponding drought are clearly reconstructed near A.D. 1150. Dean et al. (1985) observed that this drought played an important role in Ancestral Puebloan population shifts and abandonment. Cultural centers at the Virgin Branch area, Grand Canyon, northern Black Mesa, Red Rock Valley, and Chaco Canyon were all depopulated around A.D. 1150.

Following this drought, favorable conditions returned to the Four Corners area for the next 100 years, during which time the Ancestral Puebloan people made important cultural advances and achievements. Population densities, based on the number of sites, habitation units, or artifacts within the ruins, peaked in nearly all areas around A.D. 1250. However,

TABLE 3—Long-term periods of above-normal (AN) and below-normal (BN) rainfall since A.D. 100 in northwestern New Mexico based on the malpais reconstruction.

Period	Duration	Length	Sample depth[1]
AN-1	A.D. 81–257	177 yrs	6–14
BN-2	A.D. 258–520	263	5–12
AN-2	A.D. 521–660	140	5–12
BN-3	A.D. 661–1023	363	11–38
AN-3	A.D. 1024–1398	375	38–85
BN-4	A.D. 1399–1790	392	85–122
AN-4	A.D. 1791–1992	202	18–114

[1]Minimum and maximum number of measured series.

a second major short-term drought, also known as the "Great Drought," occurred between A.D. 1271 and 1296 (Douglass, 1931; Baldwin, 1935). This period "... undoubtedly contributed substantially to the widespread abandonment and population redistributions of the late thirteenth century" (Dean et al., 1985). During the previous 100 years Ancestral Pueblo populations peaked and agriculture intensified, further reinforcing a settled lifestyle. Once the climate deteriorated, rainfall became less reliable to a culture more than ever dependent on it. This may have contributed to the overall depopulation of major Ancestral Pueblo areas that occurred around A.D. 1300.

After A.D. 1400, below-normal rainfall set in and lasted until approximately A.D. 1800, forming the longest of the seven long-term periods. However, rainfall began declining as early as in the late 1200s (the "Great Drought"), and widespread abandonment of Ancestral Pueblo areas occurred, perhaps in response to these unfavorable environmental conditions. Interestingly, large settlements became established in areas with more reliable water supplies, such as the Mogollon Highlands area, the Hopi Mesas, the Zuni area, and the Rio Grande area, perhaps as a means for large populations to cope with these unfavorable climatic conditions. This aggregation of local populations was fortunate, because the worst and most severe of any of the short-term (less than 50 years long) droughts occurred between A.D. 1566 and 1608 (D'Arrigo and Jacoby, 1991).

The last of the seven long-term periods, one of very high rainfall, began around A.D. 1800 and still persists. This current period is the wettest since the A.D. 521–660 period, which is illustrated by the fact that the 1800s have the distinction of being the only century without a severe short-term drought. Below-normal rainfall did occur during certain years, such as 1806, 1819, 1822, 1847, 1851, and 1880, but these were very short-lived droughts. A major short-term drought did not occur until between A.D. 1950 to 1964, and it was one of the worst droughts in the last 2,129 years. However, rainfall following this severe drought has been unprecedented in the last 2,000 years, and researchers believe a dramatic shift in oceanic–atmospheric circulation patterns may be responsible for this increased rainfall (Miller et al., 1994). More rainfall occurred between 1978 and 1992 than in any other 15-year period during the last 2,129 years.

Conclusions and recommendations

The malpais trees reveal several long-term periods of above-normal and below-normal rainfall over the last 2,100 years. These climatic changes must have had some impact on behavioral characteristics of the populations that lived in the Four Corners area of the Southwest during the last 2,100 years. The worst long-term drought occurred between A.D. 258 and 520, and may have accelerated the differentiation of populations into the three major cultures. The change to the settled lifestyle during the Basketmaker III stage occurred during a period of highly favorable climate between A.D. 521 and 660, but populations continued to increase even during the unfavorable climate between A.D. 661 and 1023.

The worst short-term droughts during periods of population increase occurred in A.D. 1133–1161 and A.D. 1271–1296, the latter being the "Great Drought." Both droughts occurred during a long-term period of generally abundant rainfall, between A.D. 1024 and 1398. This suggests that favorable environmental conditions aided the technological advances made during that period and caused an unprecedented increase in Ancestral Puebloan populations. These large populations could not be supported during the mid-12th century and late 13th century droughts. The worst short-term drought overall occurred between A.D. 1566 and 1608, but major population centers had become established near more reliable water sources and were better able to cope with this severe drought.

The paleoclimate history revealed by the malpais trees, and the unique environment in which they live, make these old-aged conifers a natural resource unlike any other in the National Park system of the United States. Their longevity shows that the seemingly "stressful" environment offered by the malpais is perhaps not so "stressful" as it is protective. Obviously, the Douglas-fir and ponderosa pine trees find the lava flows quite hospitable. They have been able to establish, mature, and propagate on the lava flows for at least 2,000 years and perhaps much longer. The lava flows, especially the Bandera flow, afford a very protective environment, because lack of soil development and subsequent grass cover inhibit fire occurrence. Erosion processes are retarded because water rapidly seeps into the porous lava. Wild and domestic grazing animals (with the exception of the bighorn sheep) do not venture into the interior of these lava flows, and humans tend to collect wood only near the edges of the rugged lava surface.

Because the malpais region has been incorporated into the National Park system, these living trees and the remnant wood lying on the lava surfaces are guaranteed continued protection. Precautionary measures should be taken to ensure the trees of the malpais are not destroyed during activities such as road or highway clearing, building construction, or cutting for fence posts. The abundant remnant-wood samples should be protected from being collected for fuel, cut for fence posts, and being consumed in future prescribed burns. We all should treat the living trees and remnant pieces of wood found lying on the lava surface with respect and consideration deserving of extremely rare natural resources found in national parks. Additionally, there is a need for public education on the uniqueness and scientific value of the dead and living trees in the malpais to ensure their continued protection.

In the future, we would like to collect additional remnant-wood samples to eventually extend the malpais tree-ring chronology farther back into the pre-Christian Period and beyond. The possibility exists that we can eventually develop a 3,000 year long tree-ring chronology (back to 1000 B.C.) and learn more about past short-term and long-term climate fluctuations that may have affected the local populations. The possibility of developing a tree-ring chronology of such length currently does not exist elsewhere in the greater Southwest. In the future, we would like to specifically target remnants of Rocky Mountain junipers, because these trees are highly resistant to decay, are abundant throughout the malpais, and are extremely long-lived. We believe the junipers of the malpais hold the key to extending our knowledge of the climate of the Southwest over the past 3,000 years.

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